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NASA Facts

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Aircraft Energy Efficiency Program

Laminar Flow Control Technology

Fuel costs account for a sizable percent of the total operating expenses of airlines. As fuel prices climb, aircraft energy efficiency—fuel economy—takes on increasing importance.

NASA has identified technologies that in coming years can cut fuel consumption of civil air transports in half. Based on size estimates of the domestic commercial air fleet in 2005, the NASA-identified technologies would save about a million barrels of fuel daily, helping to conserve dwindling petroleum supplies and to reduce reliance on foreign oil. Fuel-thrifty air transports are of equal importance to foreign airlines, a big market for American-built aircraft.

The aviation fuel-saving technologies spotlighted by NASA are as follows:

Technology	What It Can Do
a. Engine Component Improvements	Improve propulsion efficiency
b. Advanced Engines	Improve propulsion efficiency
c. Aerodynamic Design and Control Innovations	Reduce air drag & decrease weight
d. Laminar Flow Control	Reduce air drag
e. Composite Materials	Decrease weight Structures

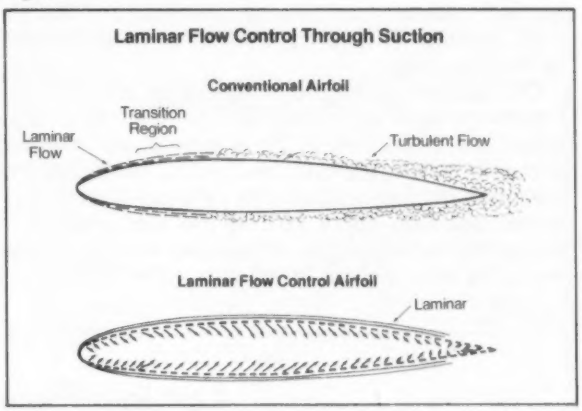
This NASA FACTS is part of a series on NASA's Aircraft Energy Efficiency research and technology development program.

Background

Laminar flow control provides the greatest potential for fuel conservation but would require a radical change in aircraft design. Estimates of fuel savings range from 20 to 40 percent, depending on the extent of application and the airplane design range.

Today's civil air transports typically cruise at about 800 kilometers (500 miles) per hour. One problem of traveling at such a speed occurs in the boundary layer, a thin sheet of flowing air that moves along the surfaces of the wing, fuselage, and tail of an airplane.

Figure 1



At low speeds, this layer follows the aircraft contours and is smooth, a condition referred to as laminar. At high speeds, the boundary layer changes from laminar to turbulent, creating friction and drag that waste fuel.

The laminar flow control concept calls for removing the turbulent boundary layer by suction, thus maintaining laminar flow. Suction requires development of porous or slotted aircraft surfaces and lightweight pumping systems.

Laminar Flow Control

When a fluid moves past a solid surface, a thin layer develops adjacent to the surface where frictional forces tend to retard the motion of the fluid. This layer is defined as the boundary layer. The boundary layer generally exists in one of three states: Laminar, where fluid particles travel along well-ordered non-intersecting paths; Transitional, where disturbances become amplified causing the smooth "layered" flow to become disrupted with some mixing of particles between layers; and Turbulent, where fluid particles from adjacent layers become totally mixed.

The state of the boundary layer is directly related to the speed and the distance the fluid has

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traveled along the surface. Transition of the boundary from laminar to turbulent results from selective amplification of disturbances which exist in the fluid stream itself or disturbances generated by irregularities and imperfections in the surface.

It has been demonstrated that the growth of these disturbances can be controlled and that a turbulent fluid state can be prevented by removing a small amount of fluid in the boundary layer. This procedure has been defined as Laminar Flow Control (LFC) (F-1).

Benefits of Laminar Flow Control

Associated with the transition of the boundary layer from laminar to turbulent is a large increase in the frictional force between the fluid and the aircraft surface. This force is referred to as viscous or friction drag.

On current commercial transport aircraft, the boundary layer is virtually always turbulent. During cruise, about half of the engine power needed to maintain level flight is required to overcome the turbulent friction drag on the external aircraft surfaces. Because about 70% of the fuel used on a transcontinental trip is consumed during cruise, reducing the friction drag can offer significant potential for fuel conservation. It has been estimated that maintenance of laminar flow over the wing and tail surfaces of long-range transports can reduce fuel consumption by 25 percent or more (F-2), the largest potential of any emerging technology. The importance of fuel conservation for commercial transports is emphasized by the fact that, at current jet fuel prices, the fuel costs amount to 40-50 percent of transport operating costs. This improvement in energy efficiency can also be translated into a longer range flight capability.

Figure 2

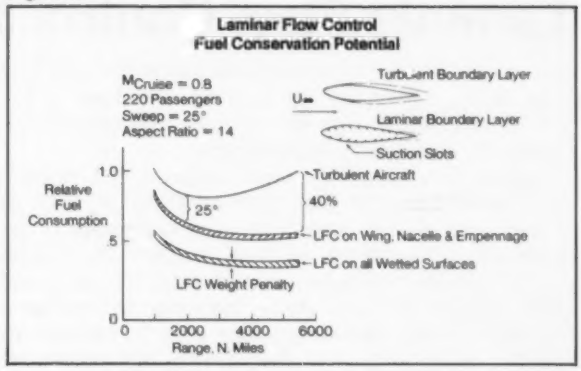
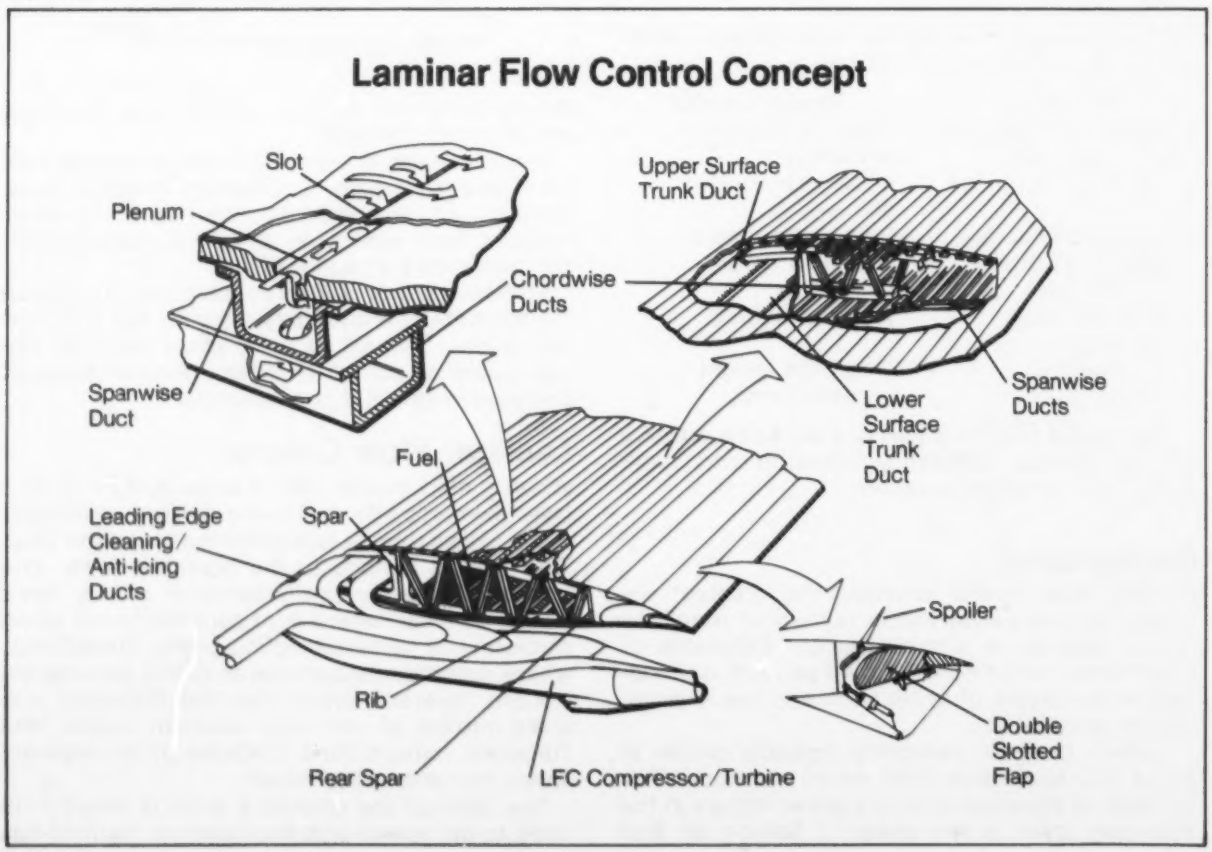


Figure 3



Laminar Flow Control System

Basically, the LFC system includes the suction surface through which a portion of the boundary layer air is taken into the airplane, a system for metering the level and distribution of the ingested flow, a ducting system for collecting the flow, and pumping units which provide sufficient compression to discharge the suction flow at a velocity at least as high as the airplane velocity (F-3).

Aerodynamicists have long known that the boundary layer can be maintained in a laminar state over large regions of airplane wings and tails through the use of LFC. The basic theory is well established, verified in wind tunnel tests, and demonstrated in various flight tests, the most notable of which was the X-21 flight research program performed by the Northrop Corporation in the 1960's under an Air Force contract (F-4). This program demonstrated that under relatively controlled conditions, laminar flow could be established and maintained over essentially all of the wing surface where suction was applied.

Laminar Flow Control Project Goals

Although these previous programs indicated the technical feasibility of LFC, they did not demonstrate operational practicality in a realistic environment nor establish the economic feasibility for commercial air transport application. Consequently, the primary goal of the NASA Laminar Flow Control Project is tc demonstrate that the technology is ready for practical application to commercial transports in the 1990's and beyond.

The LFC program focuses on the prime airframe and airline industry concerns, i.e., reliability of operation in an airline environment, and life cycle costs of LFC aircraft. Concerns about both of these aspects of LFC (F-5) must be allayed through technology development programs before the industry will be in a position to implement laminar flow control on commercial transports. Realistic manufacturing costs will be required, derived from fabrication of full-scale representative hardware and demonstrating that modern processes can economically accommodate the required exceptional tolerances in surface shape and smoothness. Acceptable means to prevent or control contamination, corrosion, and erosion of surfaces and suction systems by insect debris, dirt, ice, etc., must be found and acceptable maintenance costs, derived from a flight test program reflecting operations in an airline environment, must also be demonstrated.

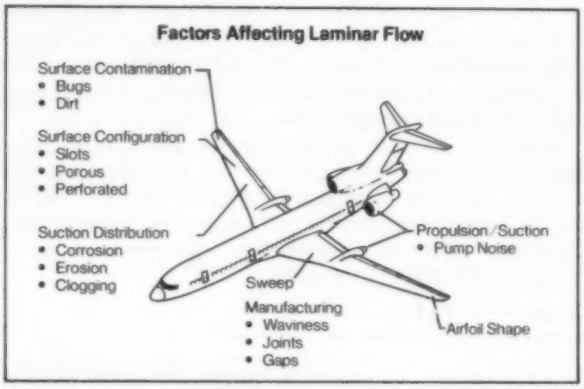
Program Guidelines

The LFC program will build upon existing LFC technology, but will utilize new materials, methodology, and manufacturing techniques where applicable to enhance the feasibility of LFC. The LFC

Figure 4

USAF X-21A Aircraft
Wing Area 1250 sq. ft
Span 93 ft, 6 in
Aspect Ratio 7.0
Sweep at .25 C 30°
T.O. WT. 83 000 lb
37% of Total Wetted Area is Laminar

Figure 5



systems investigated will be compatible with anticipated technological advances in other areas under development in the Aircraft Energy Efficiency Program such as active controls, advanced aerodynamics, composite materials, and advanced, quieter, more efficient engines. The program is structured to maximize the participation of industry with particular emphasis on involvement of current manufacturers of large commercial transports.

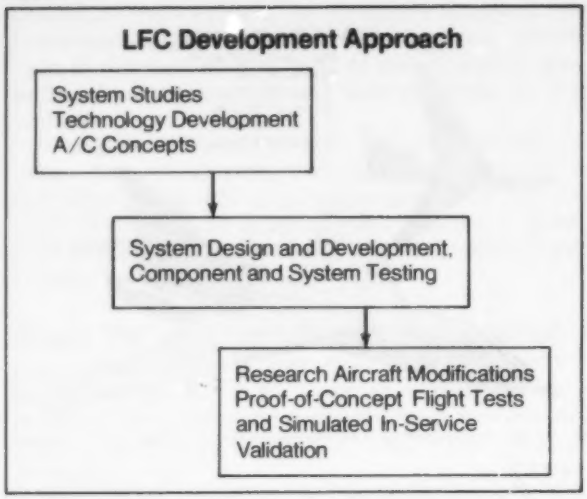
Program Plan

The plan adopted by NASA calls for a three phase program (F-6). Phase I, which was initiated in 1976 and extended through 1978, focuses on system definition and technology development. The major elements of the Phase I program are:

A. Development of Design Tools

A long term effort will be directed towards developing refined analysis methods required in design applications. Based on the latest numeric and computer technology, methods will be developed for calculating swept-wing boundary layer development and stability with surface suction. These tools will be necessary in LFC aircraft suction system designs for evaluating types of suc-

Figure 6



tion surfaces (i.e., porous, perforated, or slotted) and establishing criteria for optimum suction requirements. Experiments will be conducted to validate these design tools.

Methods will be developed for predicting the near-field noise produced by an aircraft engine and the aircraft fuselage boundary layer. These will be used to establish requirements for engine locations and for specifying allowable engine noise levels for LFC aircraft.

B. Transport System Definition

LFC systems for 1990 commercial transports will be defined through parametric studies to evaluate the performance of LFC configurations for a variety of design ranges and for off-design operation. Surfaces to be laminarized and percent of wing laminarization will be evaluated to establish the most cost-effective configurations (F-7). These efforts will provide the focus for evaluation of structural and material concepts and for identification of the most promising suction-power systems.

New materials, (F-8) such as porous composites and plastics, will be evaluated for suitability as LFC suction surfaces. Fabrication and maintenance considerations will weigh heavily in selecting the most promising materials. Perforated surfaces, ruled out in the past as practical LFC surfaces partly because of fabrication costs, could offer new promise with recently developed electron beam, laser beam, or chemmilling manufacturing techniques for perforating metals. Some in-flight testing of materials could be required, particularly for porous materials to evaluate porosity degradation in a service environment and maintenance requirements.

Structural design concepts (F-9) for both glove and load-carrying suction surfaces will be evaluated. Metals and composites will be evaluated for primary structure. Development of design

Figure 7

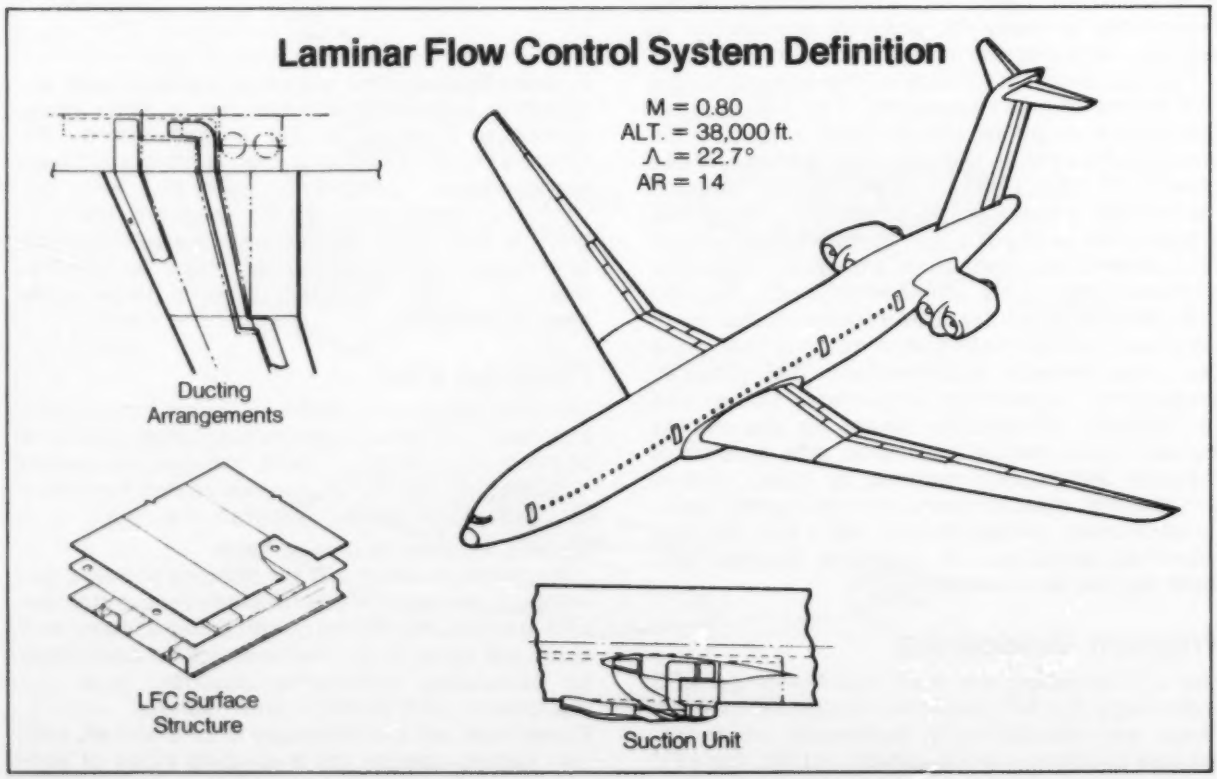


Figure 8

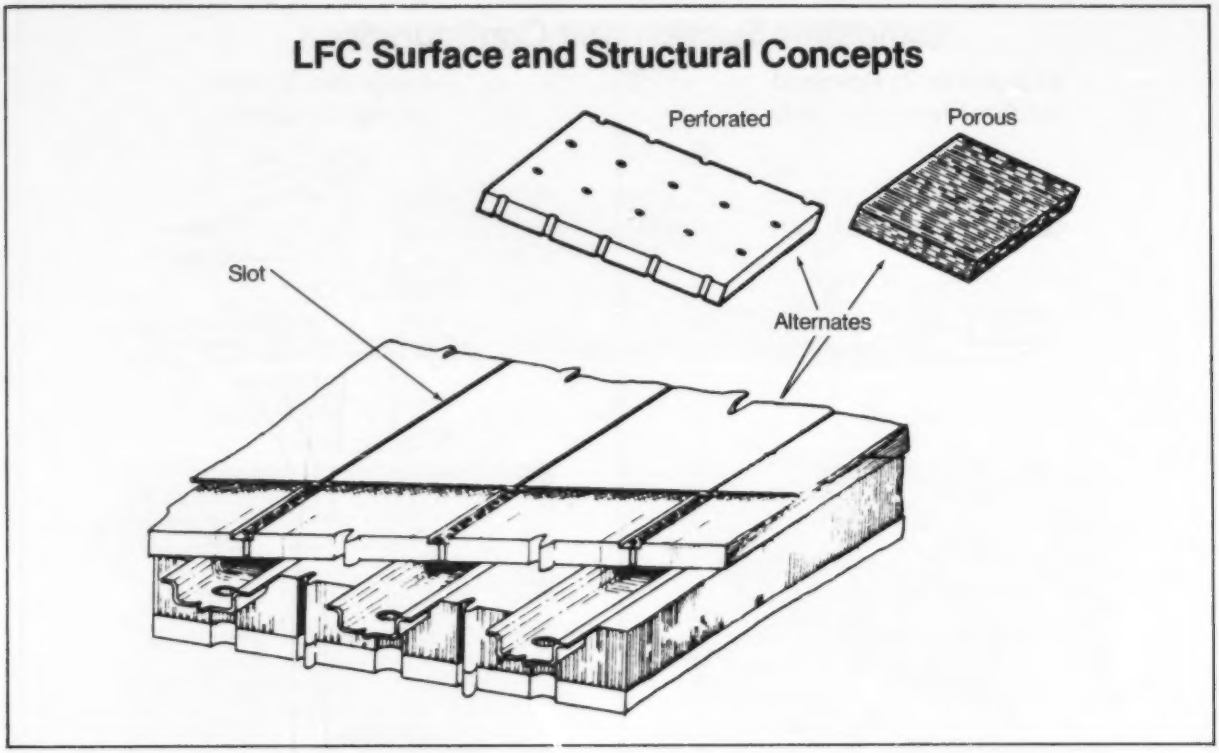


Figure 9

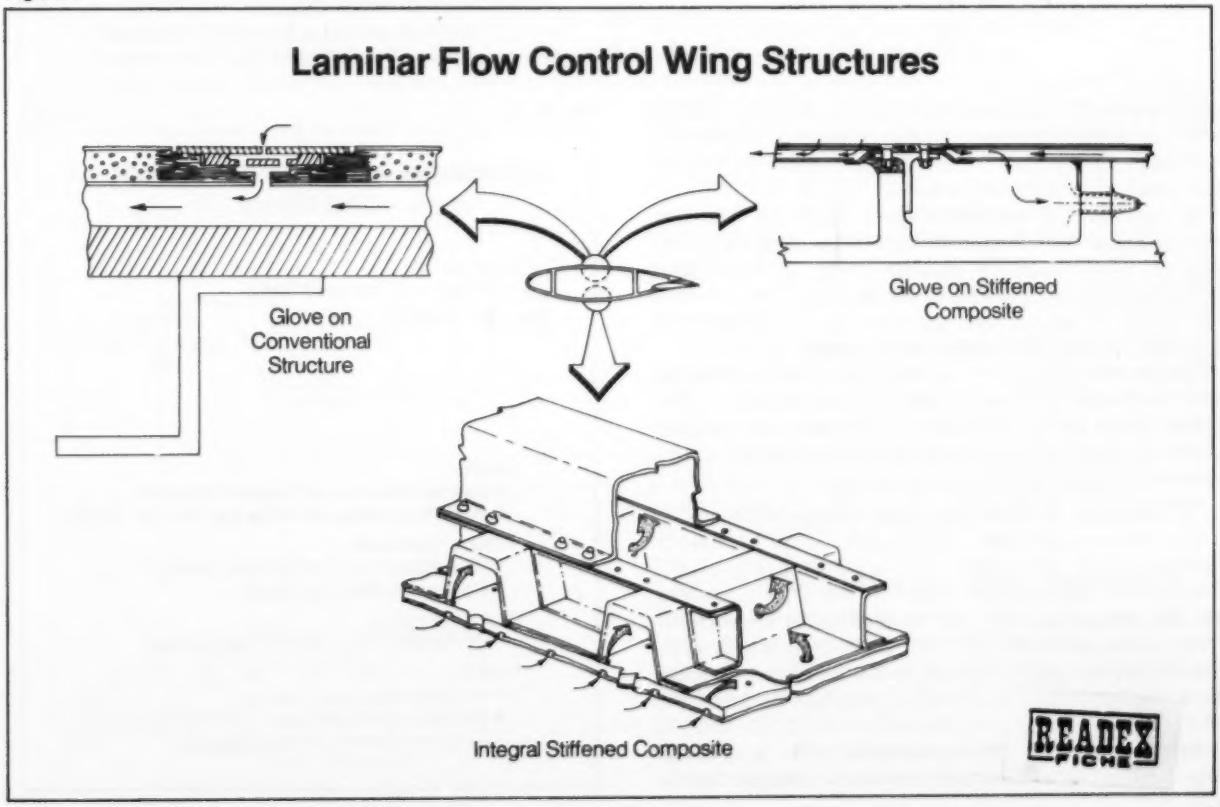
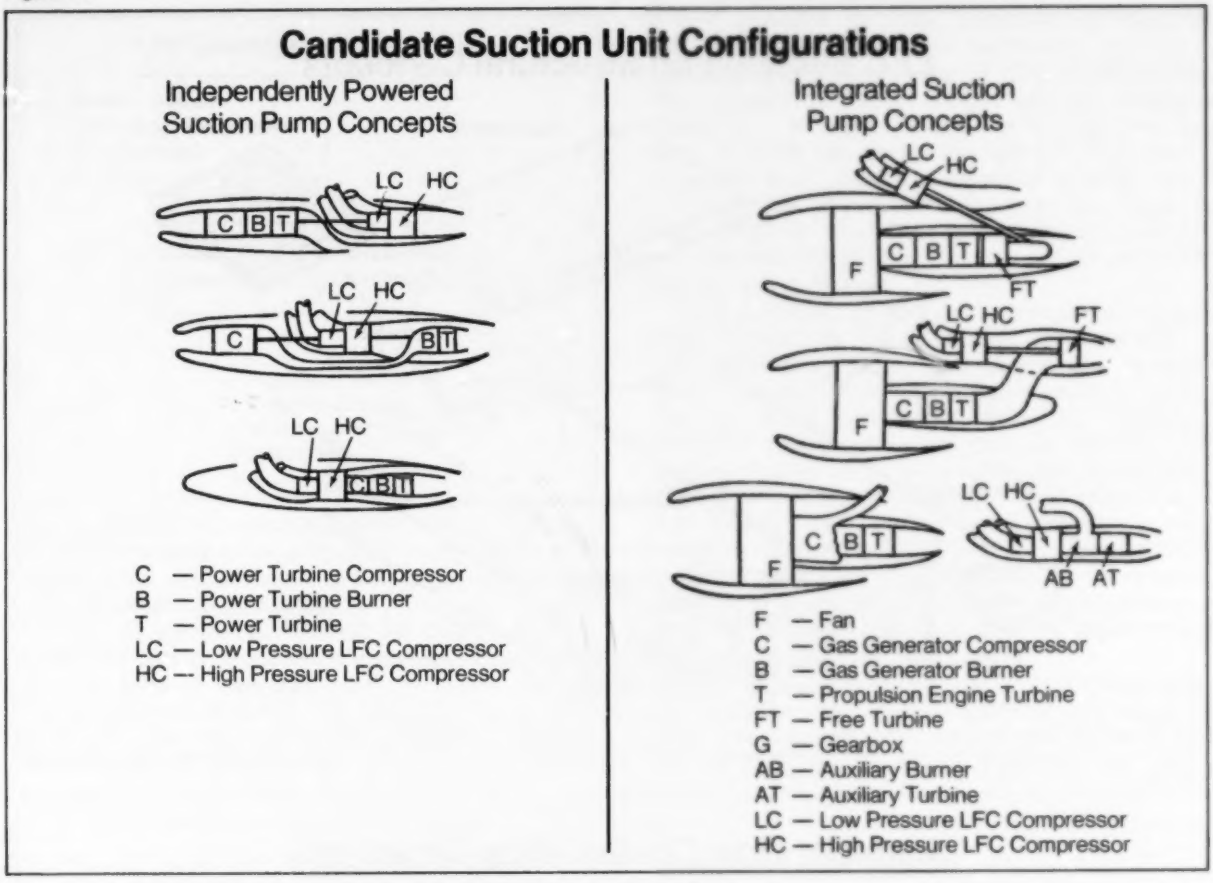


Figure 10



data through required component-level testing will be accomplished. Manufacturing feasibility will be established through fabrication of representative structural elements.

A number of suction-power options will be evaluated (F-10). These include dedicated suction-power units, suction pumps utilizing the main propulsion engines and a bleed-burn cycle, and concepts in which the suction pump shares an auxiliary power unit with other systems.

The most promising components, subsystems, and systems will be analyzed to establish life-cycle costs using the data previously developed from manufacturing, environmental tests, structural tests, component weights, etc.

C. Evaluation of Leading-Edge Contamination

Surface roughness, particularly due to insect residues, is a potentially serious problem for LFC aircraft. A successful solution to this problem would remove a major element of risk for the practical application of LFC to such aircraft. It will, therefore, be an objective to develop an acceptable approach as early in the program as possible (F-11, & F-12).

Non-adhering surface materials offer a promising and simple solution to the contamination

Figure 11

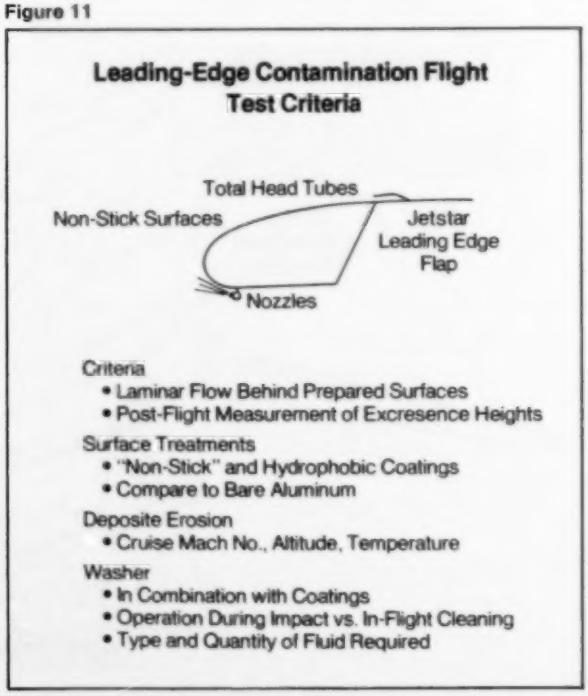

Leading-Edge Contamination Flight Test Criteria
Total Head Tubes
Non-Stick Surfaces
Jetstar Leading Edge Flap
Nozzles
Criteria
• Laminar Flow Behind Prepared Surfaces
• Post-Flight Measurement of Excresence Heights
Surface Treatments
• "Non-Stick" and Hydrophobic Coatings
• Compare to Bare Aluminum
Deposite Erosion
• Cruise Mach No., Altitude, Temperature
Washer
• In Combination with Coatings
• Operation During Impact vs. In-Flight Cleaning
• Type and Quantity of Fluid Required

Figure 12

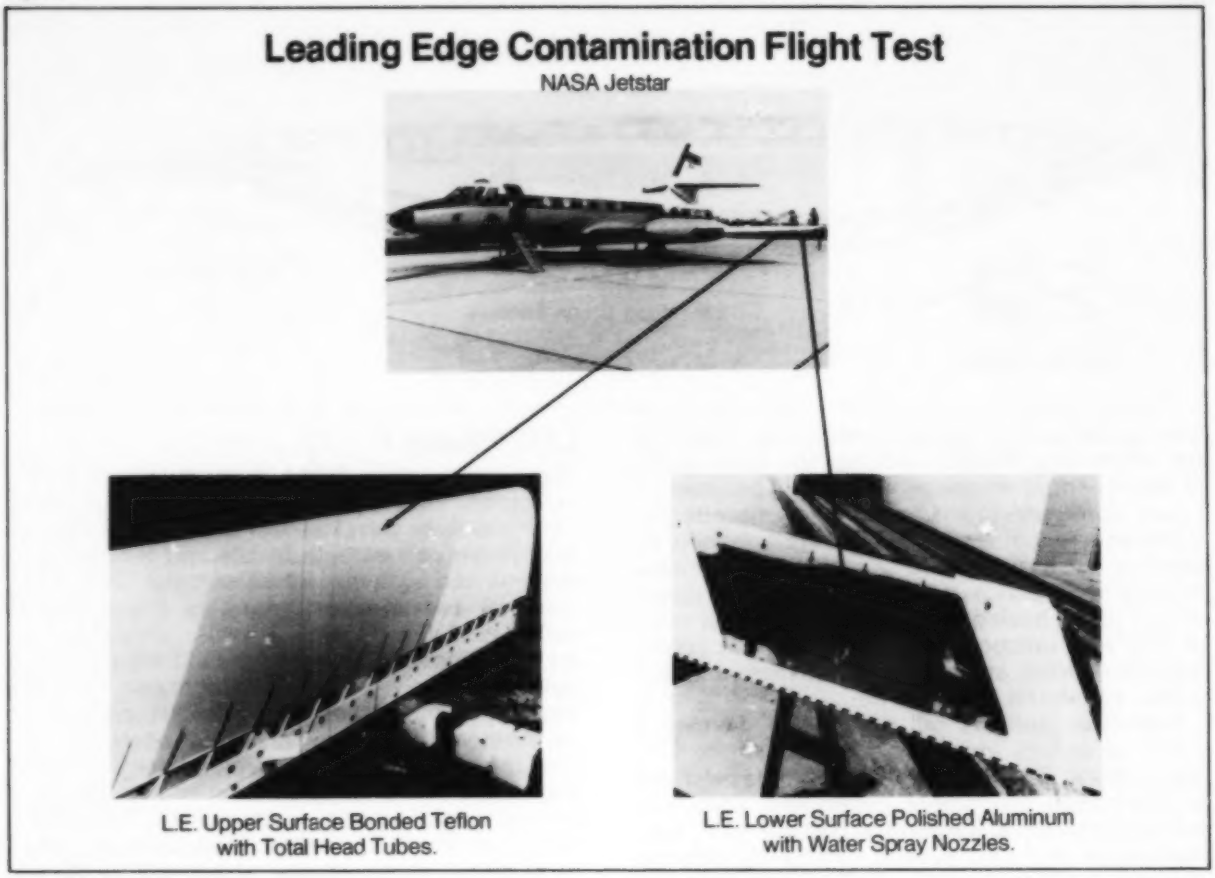
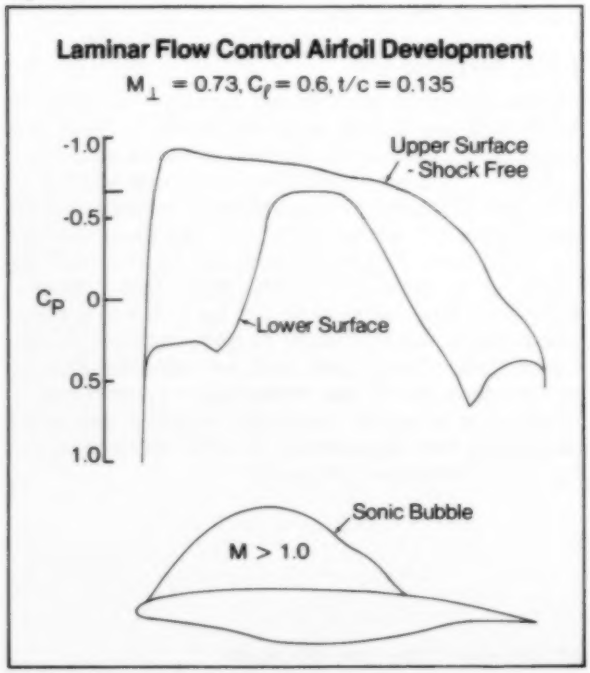

Leading Edge Contamination Flight Test
NASA Jetstar
L.E. Upper Surface Bonded Teflon
with Total Head Tubes.
L.E. Lower Surface Polished Aluminum
with Water Spray Nozzles.

Figure 13



problem. Fluorocarbon materials (such as Teflon) appear to be somewhat less easily contaminated than metal surfaces but may still be susceptible to sufficient contamination.

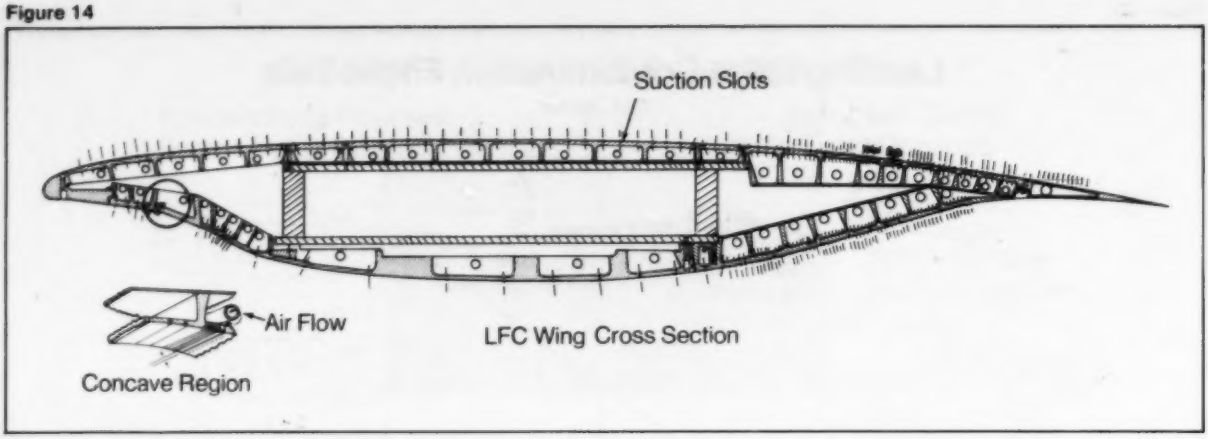
In the event that non-adhering materials are not effective, other approaches to maintain uncontaminated surfaces, such as washers, mechanical shields, or subliming materials, will be investigated.

Should a satisfactory resolution of the surface roughness question not be achievable for current cruise altitudes, an effort will be required to determine the minimum cruise altitude at which laminar flow can be achieved. Trade-offs will then be conducted to determine if the configuration and power requirements can be met in an economically viable LFC aircraft.

LFC Airfoil Design and Testing

Recent advances in airfoil design have led to large improvements in airfoil efficiency as measured by either airfoil lift, increased airfoil thickness (which results in lower structural weight or greater wing span for a given set of design conditions), or higher cruise Mach number. These new designs have been called supercritical air-

Figure 14



foils, since the flow velocity over a large region of the upper wing surface exceeds the local speed of sound. These advanced airfoils will be used on future turbulent-flow transports. Consequently, it is essential that laminar-flow aircraft designs be capable of utilizing these same types of airfoils. A major effort will be undertaken to define a supercritical airfoil having features which make it compatible with unique LFC requirements. A representative airfoil and pressure coefficient distribution are shown in F-13.

Analytical methods will be used to develop a family of airfoils which are best suited for LFC applications. Since suction levels required for laminarization are highly dependent upon airfoil characteristics, substantial reductions in suction power and LFC system complexity may be realized. A representative airfoil will be tested in a swept configuration in the Langley Research Center 8-foot tunnel. A cross section of the model depicting some of the details of the suction ducting is shown on F-14. The installation of the model in the wind tunnel test section is represented on F-15.

A series of large models will be tested at representative Mach numbers and at the highest feasible Reynolds number to allow the suction system performance to be evaluated. (Reynolds number is a measure of the ratio of inertia forces to viscous forces in a flow.) The rate of growth of disturbances in the boundary layer is directly related to Reynolds number. The results from these tests will provide basic data for the design of suction systems and also allow validation of new and improved design methods.

Figure 15

LFC Phase II

The second phase of the program, which began in October 1978 and extends through September 1982, involves development of the most promising system concepts. Subscale and full-size subsystems and systems will be designed and fabricated for extensive test programs. These include airfoil model wind tunnel tests, wing leading-edge section flight test, and ground tests of structural concepts representative of those for 1990 transports. The results from Phase II will provide verification of the suitability of advanced airfoils for LFC, continued development of promising structural concepts, operational experience with wing leading-edge systems, and demonstration of economically-viable subsystem concepts. In addition, those issues which still exist and which can only be resolved through flight validation will be identified.

LFC Phase III

Phase III activities, planned to begin in October 1982 and extend through September 1986, will include selection of an aircraft to serve as a flight validator. Design, fabrication, and qualification of the LFC systems for the validator aircraft will be accomplished along with the required aircraft modifications. Flight acceptance testing will be followed by an experimental flight test program. Following this, the aircraft will be flown in a simulated airline environment to gain realistic operational data. These data will be documented together with all of the technology developments to provide a sound basis for industry decisions regarding the application of LFC technology to future commercial transports.

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